A new reduction of USNO photographic plates of the Martian satellites

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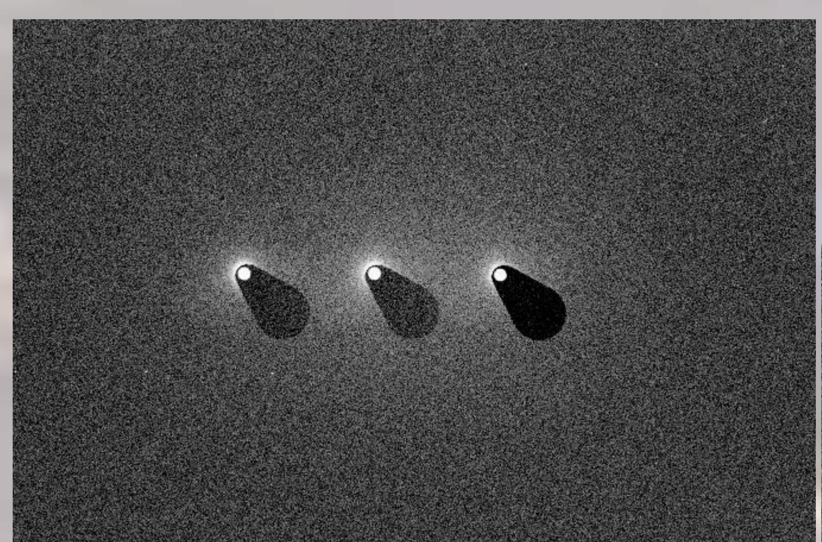
Abstract

Thanks to the new technologies, a new astrometric reduction of old photographic plates can provide a better knowledge of the orbital motion of planetary satellites.
In the cadre of the FP7 European project, USNO plates were digitized with the new generation DAMIAN scanning machine. The procedure was applied to various photographic plates and in particular to the USNO photographic plates of the Galilean satellites. The astrometric results are the most precise.

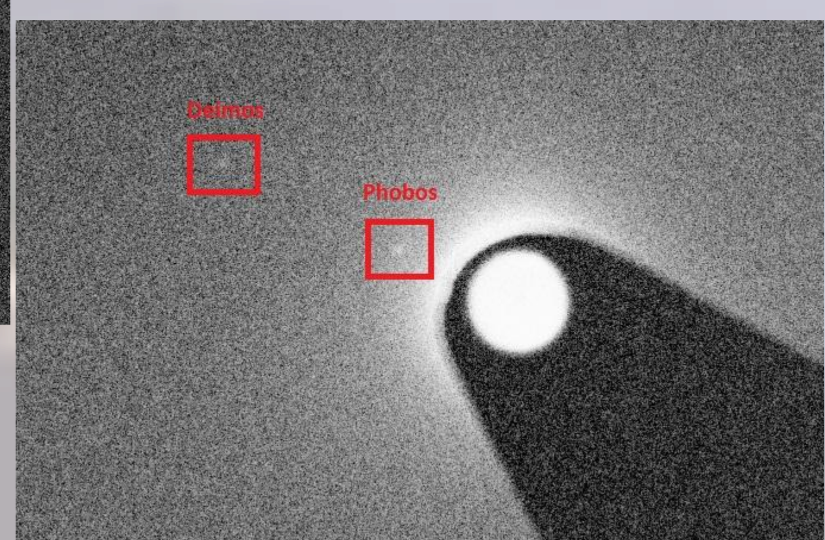
Here we consider a set of a few hundred photographic plates of the Martian satellites, taken at the USNO, and covering the years 1969-1997. A specific procedure was developed to obtain a high precision and we expect an accuracy better than 100 mas in (RA,Dec) positions of each moon. Since the position of Mars may also be deduced from the observed RA and Dec positions of Phobos and Deimos, we can also assess the accuracy of Mars' ephemeris. First astrometric results will be presented.

ESPaCE FP7 program and USNO Martian plates

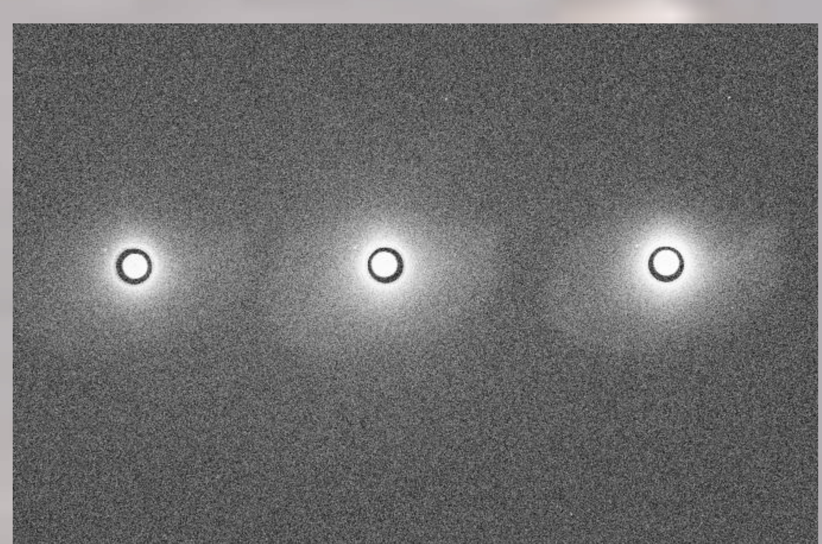
The European Satellite PArtnership for Computing Ephemerides FP7 program activity is focused on the extraction and analysis of astrometric data from space measurements not yet applied to the dynamics and to combine them with ground-based astrometric data. Part of this project aims at making accurate positional measurements of planets or satellites. The resulting astrometric data will be used to model the motions of the bodies through new SPICE kernels.
We focus here on a subset of a few hundreds photographic plates of the Martian satellites, taken with the USNO 61-inch reflector and the USNO 26-inch refractor by D. Pascu (1977, 1979 & 1994) on Kodak 103a-type from 1967 to 1997. Each plate contains from 2 to 3 observations; the exposures are shifted on the RA direction. The exposure time is about 40 sec; the field is 57' on the X-axis. All these photographic plates were recently digitized with the new generation DAMIAN digitizer (Robert et al., 2012). We present here the first results for observations from 1971 to 1997.



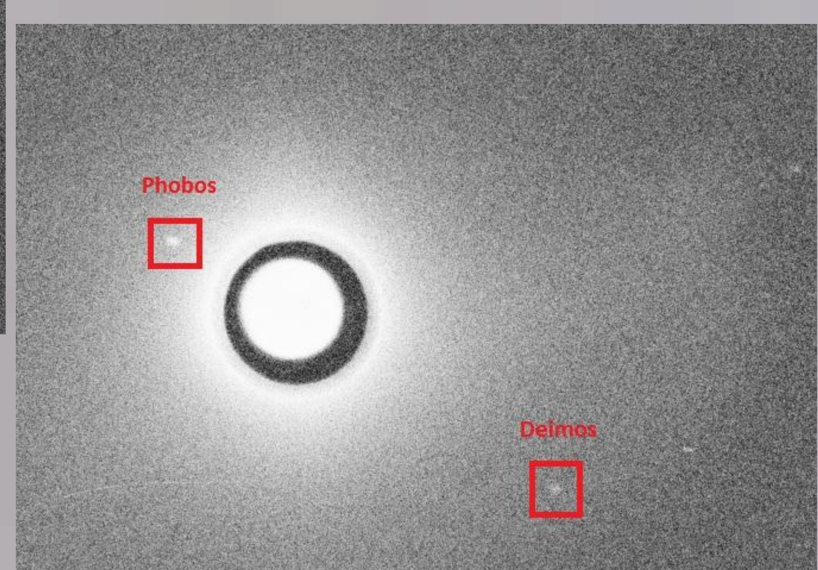
The USNO plate n°11001



Center of the USNO plate n°11001



The USNO plate n°11014



Center of the USNO plate n°11014

Extraction and identification

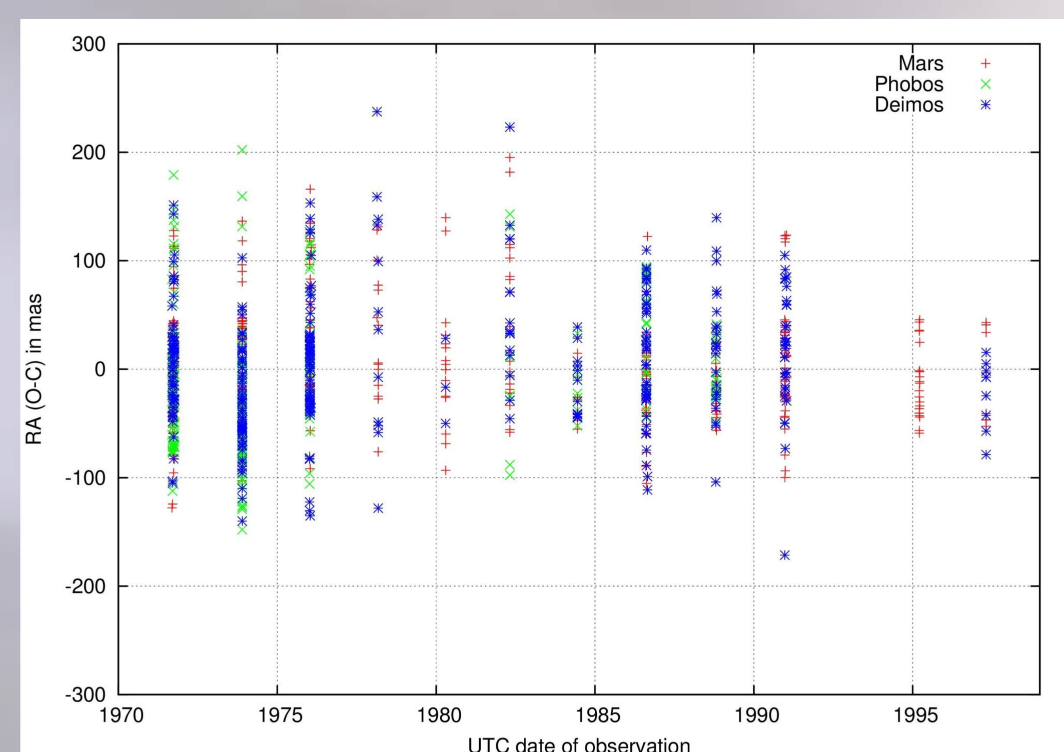
The positions on the images of the stars are extracted by means of the Source Extractor software (Bertin et al., 1996), used to create a list of objects detected on the plates. A selection for about circular objects and FWHM and magnitude constraints permit to reduce the list of possible detected sources.
The positions of the planet are extracted by an IDL ellipse fitting, the positions of the satellites are extracted by an IDL Gaussian fitting after correcting for the background gradient due to the filters' halo.
The objects assumed to be present in the field are identified from existing catalogs to select only real astrometric sources. This process defines areas on the images in which the objects have to be found (Robert, 2011). All the available stars (depending on the catalog used) are identified and more, those that are not visible with the eyes. The method can also be applied with all planetary systems; tests were successfully performed with Jupiter and Saturn USNO images, with Pluto OHP and Bucarest images.
The obtained positions are finally corrected for the optical distortion introduced by the objective/camera unit during the digitization and for the instrumental coma-magnitude effect.

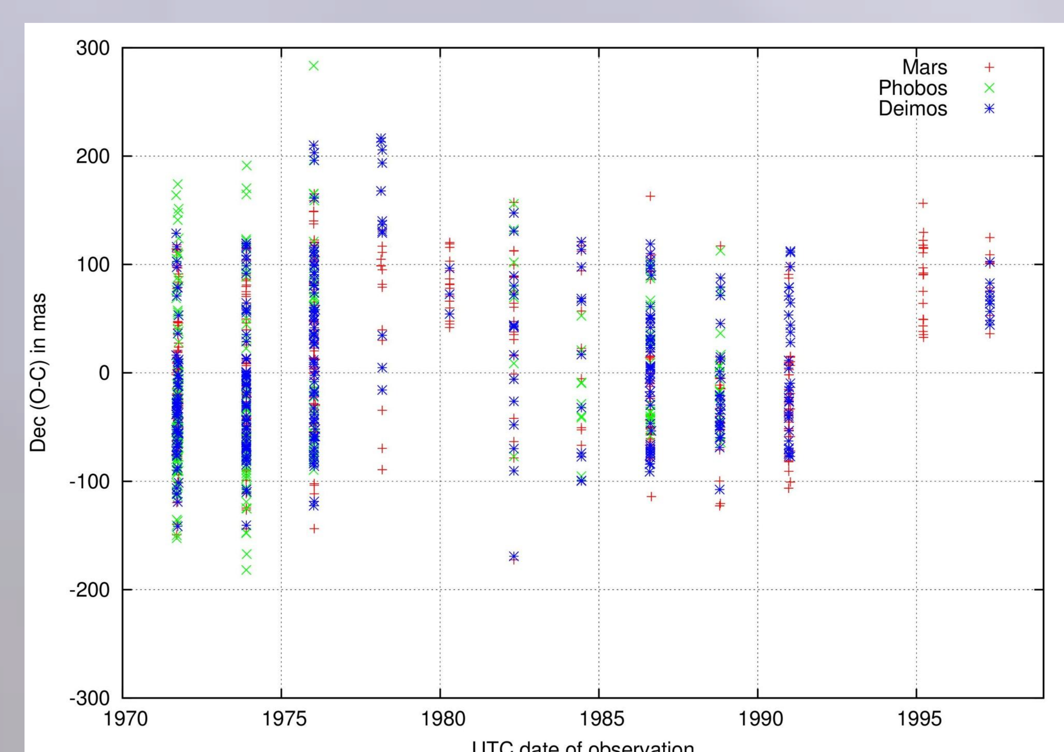
Astrometric reduction

Astrometric (RA,Dec) results of the Martian satellites and the planet are determined in an ICRS geocentric frame to be easily compared with the most recent satellite and planetary ephemerides.
Because of the few number of available stars, the astrometric reduction is quite different from a common astrometric process: the positions are here calculated after correcting for instrumental and spherical effects that take into account the parallax and aberration effects and the total atmospheric refraction.
(RA,Dec) positions are deduced from tangential apparent coordinates; the following equation system present the (x,y) → (X,Y) transformation in the case of the 26-inch observations:

$$\begin{cases} X = \rho\cos\theta\, x - (\rho+\epsilon_1\sin(\epsilon_2 t_m+\epsilon_3))\sin\theta\, y + \Delta_x + C_x x(m-m_0) \\ Y = \rho\sin\theta\, x + (\rho+\epsilon_1\sin(\epsilon_2 t_m+\epsilon_3))\cos\theta\, y + \Delta_y + C_y y(m-m_0) \end{cases}$$

Only 4 parameters modeling the scale, orientation and center of field are fitted for a minimum of 2 reference stars. The contribution of each effect is separated.





Astrometric results

The (O-C)s are for observations of Mars, Phobos and Deimos. Positions are deduced from the measurements.
Figures show details of the (RA,Dec) (O-C)s according to INPOP10 (Fienga et al., 2010) planetary ephemeris and IMCCE (Lainey et al., 2007) satellite ephemerides. The first and second tables show details of the (RA,Dec) (O-C)s and rms residuals in mas according to INPOP10 and DE423 (JPL) planetary ephemerides respectively, and IMCCE satellite ephemerides in both cases. INPOP10 and DE423 ephemerides can thus be compared. The first and third tables show details of the (RA,Dec) (O-C)s and rms residuals in mas according to INPOP10 planetary ephemeris in both cases, and IMCCE and mar097 (JPL) satellite ephemerides respectively. The two Martian ephemerides can thus be compared.

Observations compared with INPOP10 & IMCCE satellite ephemerides	$(O-C)_{\alpha\cos\delta}$	$\sigma_{\alpha\cos\delta}$	$(O-C)_\delta$	σ_δ
Mars	4.97	52.40	6.39	69.52
Phobos	-9.15	61.05	-9.01	81.52
Deimos	4.37	60.48	4.87	73.43

Observations compared with DE423 & IMCCE satellite ephemerides	$(O-C)_{\alpha\cos\delta}$	$\sigma_{\alpha\cos\delta}$	$(O-C)_\delta$	σ_δ
Mars	3.78	52.38	6.00	69.86
Phobos	-10.56	61.10	-9.82	81.69
Deimos	3.08	60.55	4.40	73.70

Observations compared with INPOP10 & JPL satellite ephemerides	$(O-C)_{\alpha\cos\delta}$	$\sigma_{\alpha\cos\delta}$	$(O-C)_\delta$	σ_δ
Mars	4.97	52.40	6.39	69.52
Phobos	-8.53	60.99	-7.94	81.36
Deimos	2.67	60.85	5.10	73.40

Conclusion

We demonstrated the high interest to continue the analysis of old photographic plates such as USNO's. Thanks to the new technologies, we were able to provide astrometric data with a high accuracy after applying the necessary corrections.
We now provide an accuracy about of 70 mas for (RA,Dec) positions of the planet and its moons. Note that the previous accuracy was about of 200 mas and only for relative positions. More important, these results indicate that we now can reach an accuracy better than that of CCD observations (Colas et al., 1991) and as good as the old spacecraft measurements of the system. These results encourage us to continue the analysis of old photograhic plates.
We have at the present time a set of several hundred USNO plates of the Saturnian system. The digitization and new reduction are also part of the FP7 European project. The step after will be to reduce other relevant old photographic plates such as Yale Southern Station Saturnian observations.

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